

****FULL TITLE****

*ASP Conference Series, Vol. **VOLUME**, **YEAR OF PUBLICATION***

****NAMES OF EDITORS****

The Outer Cut-Off of the Giant Planet Population and the 6pc-Survey

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Abstract. We present results from two high-contrast imaging surveys that exploit a novel technique, L-band angular differential imaging. Our first survey targeted 21 young stars in the β Pic and Tuc-Hor moving groups with VLT/NACO reaching typical sensitivities of $<1 M_{Jup}$ at $r > 20$ AU. The statistical analysis of the null result demonstrates that the giant planet population is truncated at 30 AU or less (90% confidence level). Our second, on-going MMT/Clio survey utilizes the unique sensitivity achieved in the L-band for old planets to probe all M-dwarf stars within 6 pc. The proximity of these targets enables direct imaging of planets in orbits like Jupiter for the first time — a key step for directly imaging giant planets.

1. General Introduction

The study of exoplanetary systems is arguably the most rapidly developing field in modern astrophysics. Surprisingly, much progress has been made without directly imaging a single planet: radial velocity/microlensing and primary and secondary planet eclipses provide limited, but valuable insights. Direct imaging of planetary systems will have a fundamental impact on the field — a single, low-resolution 3–5 μm spectrum of a planet may carry more information than all existing Spitzer transit photometry combined. As was the case in the search for the first brown dwarf, or for radial velocity and planet transit techniques, achieving the first firm detection is a very difficult and often frustrating challenge. But these investments paid off rapidly by opening whole new classes of objects for study.

2. L-band Angular Differential Imaging

Using rotational subtraction of the persistent speckle pattern and the image artifacts, adaptive optics systems are capable of reaching very high contrast. Low thermal-background telescopes, such as Very Large Telescope (VLT) and the Multiple Mirror Telescope (MMT), can utilize this technique in the L-band where the superior adaptive optics-correction (Strehl ratios 80%–90% vs. 30–45% in H-band) further increases the contrast. Our recent VLT/NACO L-band observations routinely achieved $\Delta L=11$ mag contrast at 1" and larger

separations. This contrast, in combination with the typical color of older planets ($H-L=5.5$ mag, 2 Gyr, $5 M_{Jup}$, Baraffe et al. 2003), provides more than 1 mag sensitivity increase over spectral differential imaging (Kasper et al. 2007).

3. The Scarcity of Giant Planets at Large Separations

Using the L-band angular differential imaging technique on the VLT/NACO we carried out a survey of 21 young stars, members of the nearby Tucana–Horologium (10–30 Myr) and the β Pictoris moving groups (~ 12 Myr). No substellar companions were found around the target stars, but the companion to 51 Eri, GJ 3305, was found to be a very close binary on an eccentric orbit. Our sensitivity would have allowed the detection of companions as small as a Jupiter mass at orbital distances typically of 5 AU.

The absence of detected companions sets constraints on the frequency and maximum orbital distance of giant exoplanets. We show that a radial distribution of planetary companion with a maximum orbital radius exceeding 30 AU — in combination with a power-law index of 0.2 — can be rejected at a 90% confidence level (see, Fig. 1 and Kasper et al. 2007). This demonstrates that giant planets are relatively rare at large separations. A similar conclusion was reached subsequently by other independent surveys (e.g. Lafreniere et al. 2007).

4. Imaging Planets on the Scale of our Inner Solar System

The result of our NACO survey also offers an explanation of why most current and past direct imaging surveys failed to detect a giant planet population: most of these focus on near-infrared wavelengths ($1\text{--}2.2\ \mu\text{m}$), representing a trade-off between the rise of the thermal background toward the longer wavelengths and the adaptive optics performance degrading toward the shorter wavelengths. *However, the fact that the $1\text{--}2.2\ \mu\text{m}$ flux of giant planets rapidly declines with time limits the age of the ideal target stars to less than 30–50 Myr.* Because young stars are typically at 40 pc or beyond, even the highest-order adaptive optics-based systems can only probe the outskirts ($>1''$ or >40 AU) of these exoplanetary systems, where giant planets are rare (Kasper et al. 2007).

The key novelty of the L-band angular differential imaging is that it is also sensitive to planets as old as a few Gyr. This enables the study of relatively old nearby stars, whose proximity allows us to directly planets on orbits comparable to that of Jupiter ($r > 3$ AU).

Exploiting the strength of this technique we are carrying out a 6 pc volume-limited survey of M-stars using the MMT/Clio 3–5 camera (e.g. Hinz et al. 2006). With 14 allocated nights we are covering 35 northern M-dwarfs within 6 pc. The M-dwarf survey will complement the Sun-like star survey of Heinze et al. (in prep.) surveying the complete stellar population within 6 pc. The survey is currently about 2/3 complete and the data reduction and analysis is ongoing (Apai et al., in prep.).

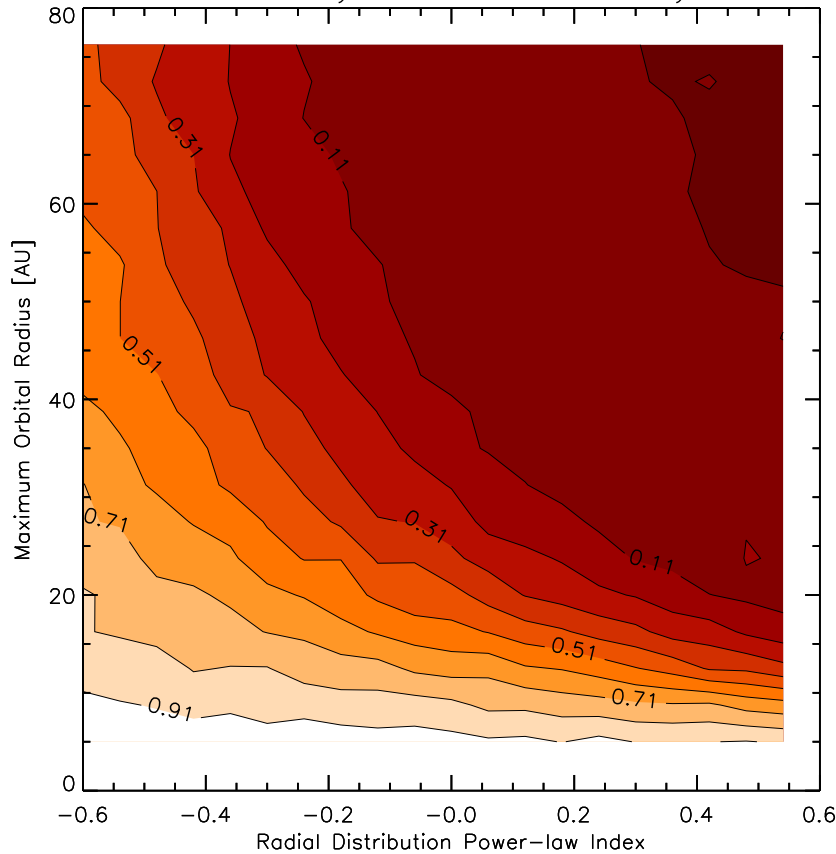


Figure 1. Map of probability that the planet population simulated for a given $dn/da \sim a^{-\alpha}$ and r_{max} value is consistent with only non-detections in our VLT/NACO survey.

5. Conclusions

We present results from a novel high-contrast imaging technique. Our NACO survey of 21 nearby young stars demonstrates that the giant planet population does not extend beyond 30 AU and suggests a cut-off at radius < 15 AU. Most previous imaging surveys have not detected planets because they targeted young stars (> 20 pc) forcing them to probe orbital radii > 20 AU. Our ongoing MMT 6pc volume-limited survey is probing — for the first time — the massive giant planet population around the closest stars with orbital radii > 3 .

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